EFFECTS OF TASK-IRRELEVANT SOUNDS ON THE TACTILE PERCEPTION OF ROUGHNESS

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Abstract

Previous studies demonstrated that tactile sensations of surface roughness were affected by touch-produced sounds. We investigated whether task-irrelevant sounds differentially modified the tactile estimation of roughness and length. The results revealed that only white noise had a significant effect on the roughness estimations. Further, we investigated whether the same tendencies can be observed in the tactile roughness perception of smoother surfaces near the threshold level. The analyses of discrimination errors verified that the tactile roughness perception was modified by the auditory stimuli only in the coarser pair. In particular, white noise and pure tones affected the roughness in opposite ways: the white noise led to rougher sensations and the pure tones led to smoother sensations. The results suggest that task-irrelevant sounds modify the tactile roughness perception. However, it is indicated that the effects likely occur in a limited range of tactile surfaces or in the appropriate combinations between surface roughness and sounds.

When we touch and explore textured surfaces, sounds are usually produced. Katz (1925) pointed out that when we touch objects by moving our hands on the surfaces, the pressure sense is usually accompanied by the sense of vibration, which is closely linked to auditory perception. Previous studies have demonstrated the effects of touch-produced sounds on texture perception. Jousmäki and Hari (1998) reported that the roughness/wetness perception of the palmar skin was altered by the feedback of the sounds produced by rubbing both hands. In their study, either the high-frequency component or the overall frequency of the touch-produced sounds was amplified or attenuated and fed back to the participants through headphones in real time. In the results, both types of amplifications increased the perception of smoothness/dryness of the palmar skin; therefore, the sound effect was termed "parchment-skin illusion." Guest, Catmur, Lloyd, & Spence (2002) repeated the study of Jousmäki and Hari (1998) and reported that the amplification of the high-frequency component of the auditory feedback increased the perception of the roughness and dryness of the surfaces of the hands. In addition, the perception of dryness also increased with overall amplification.

Besides the surfaces of the hands, Guest et al. (2002) demonstrated the effects of auditory feedback on the roughness perception of abrasive papers. They used two particle sizes of the abrasives. The participants of their study were instructed to ignore the sounds and judge whether the presented sample is smoother or rougher one. When the participants touched the abrasives, touch-produced sounds were unmodified, attenuated, or amplified in the range of 2–20 kHz and fed back to the participants through the headphones. Their results showed that high-frequency attenuation caused the roughness of the stimulus to be perceived as smoother, whereas amplification resulted in it being perceived to be rougher.

Lederman, Klatzky, Morgan, & Hamilton (2002) conducted magnitude estimations of roughness using plastic plates and a probe. Their results showed that estimated roughness was the largest in the haptic-only condition and the smallest in the auditory-only condition. Further, in the bimodal condition, it was between these smallest and largest values but biased toward the magnitude of the haptic-only condition. The stimuli used by Lederman et al. (2002) contained raised elements in the form of truncated cones, which have inter-element spacing ranging from 0.500 to 3.125 mm. On the other hand, Suzuki, Suzuki, & Gyoba (in press) used abrasive papers with particle diameters ranging from 0.015 to 0.275 mm. In the experiment of Suzuki et al., participants were instructed to ignore the sounds produced by touching stimuli and fed back though the headphones. The tactile roughness of the stimuli was estimated using the magnitude estimation method. Unlike the results of Lederman et al. (2002), Suzuki et al. showed that the exponents (i.e., the slopes of the roughness estimation function) with sound feedback were smaller than those without the sounds.

Although these studies used touch-produced sounds, there is a possibility that task-irrelevant sounds also modify the tactile roughness perception. In particular, complex sounds such as white noise are acoustically similar to touch-produced sounds, in the sense that they contain broadband components in frequency. Schiller (1932) pointed out that tone affected texture perception. However, few studies have quantitatively investigated the effects of task-irrelevant sounds on roughness perception.

Recent neuroimaging studies of humans or macaque monkeys have provided evidence for the involvement of the cortices in the integration of touch and audition (e.g., Foxe, Wylie, Martinez, Schroeder, Javitt, Guilfoyle, Ritter, & Murray, 2002). In the intra-modal domain, recent PET studies reported that the discriminations of tactile roughness and shape/length activate different cortical regions (Roland, O'sullivan, & Kawashima, R. (1998). Therefore, we predicted that if the auditory processing of complex sounds and the tactile processing of roughness contain a common basis, the sounds might selectively modify the tactile roughness perception.

In the present study, we investigated whether non-informative task-irrelevant sounds such as white noise or pure tones affect tactile roughness and length perception (Experiments 1A and 1B). In addition, we compared the effects of the sounds on the tactile roughness perception of a finer surface with those on the perception a coarser surface (Experiment 2).

Experiment 1

The purpose of Experiment 1 was to investigate whether the tactile roughness perception would be selectively modified by task-irrelevant sounds in quantitative analysis. In Experiment 1A, the effects of white noise on tactile roughness were examined in comparison to those of beeps. In Experiment 1B, the effects of pure tones were investigated as one of the other task-irrelevant sounds.

Method

Ten and eight students participated in Experiments 1A and 1B, respectively. As the tactile stimuli, 14 particle sizes of silicon carbide abrasive paper (grid value: 60–1200) were used in the roughness estimation, and 14 length of abrasive paper (1.7–18.0 cm; all the stimuli were 3 cm in width and of the same grade: 240) was used in the length estimation. In Experiment 1A, as the auditory stimuli, white noise whose intensity level (about 53, 58, 64, and 69 dB) changed at 1-sec intervals in the pseudo-random order was used. In Experiment 1B, a pure tone whose intensity level (about 57, 60, 66, and 71 dB) changed at 1-sec intervals was presented. In both the experiments, beeps (1000 Hz, 50 ms, 5 times, SOA = 1 sec) were used as control stimuli.

In each experiment, both the tactile roughness estimations and length estimations were conducted in separate blocks. Participants wore headphones (Audio-technica ATH-PRO700) and touched the abrasive paper with the index finger and middle finger of the dominant hand. They synchronized their touch with the intensity changes in the white noise (Experiment 1A), the pure tones (Experiment 2B), or with the onset of the beeps (the control condition in both the experiments). The participants made absolute magnitude estimates of the "roughness" or "length" of the abrasive paper. Based on the absolute magnitude estimation procedure (e.g., Gesheider & Hughson, 1991), no standard or modulus was used, and the participants could use any subjective impression of roughness or length that they felt comfortable with.

In Experiments 1A and 1B, 14 tactile stimuli of roughness and length were divided into two types of complementally selected seven samples and were presented in different auditory conditions (blocks) in a counterbalanced manner. The order of the task (the roughness or length estimations) and the presentation of the auditory stimuli (the white noise or beeps in Experiment 1A; the pure tones or beeps in Experiment 1B) were also counterbalanced across the participants. Each abrasive paper sample was presented four times in random sequence, including one trial in which it was presented for practice. In total, the participants judged both the roughness and length 56 times.

Results and Discussion

For two auditory conditions, the mean magnitude estimates of the perceived tactile roughness and length for each participant were logarithmically transformed and plotted as a function of the logarithmic grid size of each stimulus. From the equations obtained by a least squares method, the slopes (i.e., exponents) and coefficients of determination of the equations were calculated for each participant.

Fig.1. shows the functions based on the mean slope and intercept across the participants in Experiments 1A and 1B. In Experiment 1A, one participant was excluded from the analysis because the slopes exceeded the mean by greater than two standard deviations.

The data were then analyzed by a repeated-measures ANOVA with Sound (white noise/beeps) and Task (roughness/length) as factors. The results showed that the Sound × Task interaction was significant (F (1, 8) = 12.06, $p < .01$). The simple main effect of Sound in the slopes was significant only in the roughness estimations (F (1, 16) = 5.55, $p < .05$).

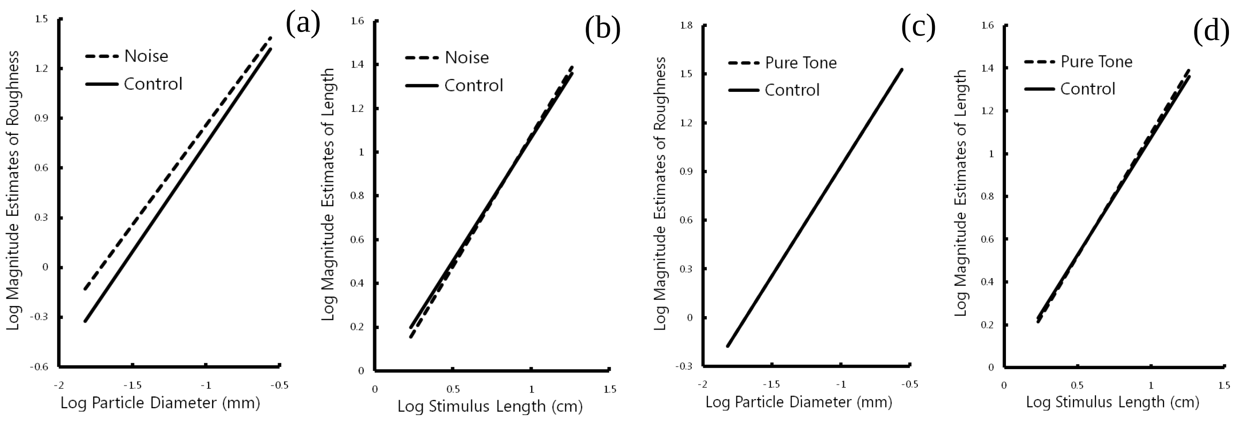

Fig.1. (a) and (c) indicate the functions of the tactile roughness estimates in Experiments 1A and 1B.
(b) and (d) show the functions of the tactile length estimations in Experiments 1A and 1B.

The post hoc comparisons by Ryan's method (where $p < .05$ prior to correction) revealed that the slopes of the roughness estimation function of the white noise condition (mean = 1.20) were significantly smaller than those of the control condition (mean = 1.30). There were no significant main effects in the coefficient of the determination of the equations.

We examined whether the tactile roughness perception was selectively affected by the white noise, which was the task-irrelevant sound in Experiment 1A. The results showed that when the participants touched the tactile stimuli while synchronizing the movement of their finger with the intensity change of the white noise, the slopes of the tactile roughness estimation function was modified toward to be significantly less steep.

In Experiment 1B, data were analyzed in the same manner as in Experiment 1A. The difference from Experiment 1A was that the sound stimuli were pure tones instead of white noise. The results showed that there were no significant main effects or interactions in both the slopes and the coefficient of determination of the equations.

The results obtained from Experiments 1A and 1B showed that the touch while hearing white noise selectively modified roughness perception. The white noise significantly decreased the exponents of the roughness estimation function, although it did not affect the length estimation. In comparison with white noise, the pure tones affected neither the roughness nor the length perception. These results revealed that complex sounds like white noise can selectively modify the tactile roughness perception, even when they are seemingly irrelevant to the touch. Thus, these findings are in line with neuroimaging studies, which indicate that the tactile information processing of roughness and the auditory information processing of complex sounds may contain a common basis.

Experiment 2

The purpose of Experiment 2 was to compare the effects of touch-irrelevant sounds on the tactile roughness perception of a finer surface with those on the perception of a coarser surface.

Method

Seventeen students participated in Experiment 2. The tactile stimuli were two pairs of aluminum oxide abrasive paper, with grit values of 1200 and 4000 as a coarse pair, and 400 and 600 as a fine pair. The auditory stimuli were white noise (about 62 dB), 1000 Hz pure tones (about 64 dB), and clicks. The loudness of the pure tones was subjectively matched with that of the white noise by each participant. All auditory stimuli were presented twice. The duration of the white noise and pure tones was 500 ms, and the interval between the sounds was 50 ms. The clicks were presented at the onset of the white noise or pure tones.

The participants wore headphones (Audio-technica ATH-PRO700) and touched the abrasive paper with the index finger of the dominant hand, while synchronizing the scrolls with the onset of the sounds. The task was categorizing the presented sample as either the rougher or smoother one of the pair. Before the experimental session, the participants were allowed to touch the samples freely and trained in the discrimination task. During the training session, only the clicks were experienced and error feedback was provided. After the correct performance exceeded 12 trials in the last 15 trials, the experimental session was started. During the experiment, the coarse pair and the fine pair were presented in the separate session and counterbalanced across the participants. In the experimental session, four blocks that contained each of the 45 trials included all sound conditions.

Results and Discussion

The data from Experiment 2 are presented in Fig.2. The error data in each sound condition for each participant was calculated separately for each of the pairs and for the rough and smooth samples. Then, the data for each of the coarse and fine pairs were separately analyzed by a repeated-measures ANOVA with Sample (rough/smooth) × Sound (white noise/pure tone/click) as factors.

In the coarse pair, there was a statically significant Sample × Sound interaction (F (2, 32) = 9.34, $p < .001$). The simple main effect of the Sample was significant only in the white noise condition (F (1, 48) = 14.51, $p < .001$), indicating that in the white noise condition, participants committed more errors for the smooth sample than for the rough sample. The Sound simple main effect was significant for both samples (rough: F (2, 64) = 4.78, $p < .05$; smooth: F (2, 64) = 4.66, $p < .05$). The post hoc comparisons (Ryan's method, $p < .05$) showed that significant differences were found between the white noise condition and the pure tone condition for both the rough and smooth samples. In the rough sample, more errors were made for the pure tone than for the white noise condition. Reversely, in the smooth sample, more errors were made for the white noise than for the pure tone condition. The main effect of Sample was marginally significant (F (1, 16) = 4.32, $p < .01$) and indicated the tendency that more errors were made overall for the smooth (mean = 0.16) than for the rough sample (mean = 0.10). In the fine pair, there were no significant main effects or interaction.

These results showed that the effects of touch-irrelevant sounds were observed for the coarse but not for the fine surface. In particular, for the coarse surface, the white noise led to rougher sensation and the pure tone had an opposite effect. However, for the fine surface near the threshold level, the effects of the sounds on tactile roughness were not found. There are several plausible reasons for this asymmetry of the sound effects. First, task-irrelevant sounds might modify tactile sensation in a limited range of surfaces. For example, it is plausible that sounds have no effects on the surfaces that are outside the considered range.

Another possibility is that appropriate correspondence between sounds and the surface may be necessary for the interaction between the sounds and tactile perception of roughness. In the present study, three types of sounds (including click) were used. Complex auditory stimuli such as white noise were reported to cause the spatial modulation of audio-tactile interactions greater than the pure tones (Kitagawa, Zampini, & Spence, 2005). However, the results from Experiment 2 showed that besides the white noise, tactile roughness was also modified by the pure tone. Therefore, it is necessary to investigate

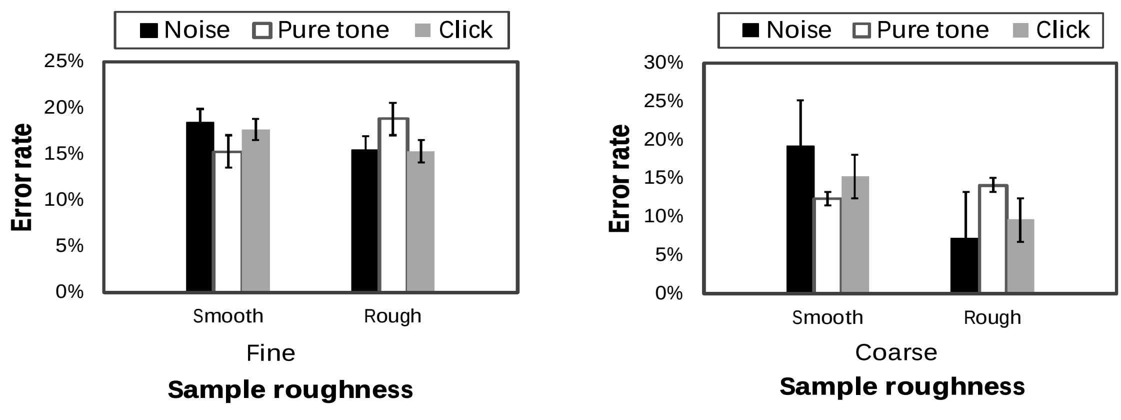

Fig.2. Error rates for the three sound conditions (noise, pure tone, and click) in each of the samples (smooth and rough). The left side is for the fine pair, and the right for the coarse pairs. Error bars indicate standard errors.

whether audio-tactile interaction would occur depending on the correspondence between the surface texture and auditory stimuli.

General Discussion

The present study psychophysically investigated the effects of task-irrelevant auditory stimuli on the tactile perception of roughness. The results from Experiment 1 revealed that white noise alters the tactile roughness estimation function toward less steep, although it does not affect tactile length estimation. The results suggest that tactile roughness and auditory information processing may contain a common basis. Contrary to the results of Experiment 1, which indicated that the pure tone had no effect on both tactile roughness and length, Experiment 2 showed that the pure tone also affected the tactile roughness perception of the coarse surface. In contrast to the white noise, which led to rougher sensation, the pure tones induced smoother perception. The modification effects of the sounds on tactile roughness were found for the coarse stimuli (400 and 600 grades) but not observed for the fine stimuli (1200 and 4000 grades). The difference between the results of Experiment 1 and Experiment 2 may indicate that audio-tactile interaction occurs depending on the range of tactile stimuli or the appropriateness of the correspondence between tactile stimuli and auditory stimuli (e.g., complexness, intensity level, or pitch). Further experiments are necessary to examine the validity of the two possibilities raised by the present study.

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